

NASA CENTER UPDATE GODDARD SPACE FLIGHT CENTER

Presented to
1992 NASA AEROSPACE BATTERY WORKSHOP

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NASA GODDARD SPACE FLIGHT CENTER UPDATE

- **SPACECRAFT OPERATIONS**
- **LIFE CYCLE TESTING AT NAVAL SURFACE
WARFARE CENTER (NSWC), CRANE, INDIANA**
- **DESTRUCTIVE PHYSICAL ANALYSIS (DPA) AT
COMSAT LABORATORIES, CLARKSBURG,
MARYLAND**
 - Ms. Kathleen Robbins from COMSAT is presenting the DPA data later in the morning at this Workshop

SPACECRAFT OPERATIONS

- Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX)
- Extreme Ultraviolet Explorer (EUVE)
- Upper Atmosphere Research Satellite (UARS)
- Compton Gamma Ray Observatory (GRO)
- Earth Radiation Budget Satellite (ERBS)
- Hubble Space Telescope (HST)

SAMPEX

- Single 9 Ah Super NiCd battery
- 22 series cells per battery
- Plate fabrication in 10/90
- Cell activation in 5/91
- Launched on 7/3/92
- Completed 1545 eclipse orbits and 525 full sun orbits
- Nominal performance
 - VT 5, recharge ratio 1.04, temperature 2 - 11°C, and average DoD 12% (maximum 17.2%)

EUVE

- Three 50 Ah conventional NiCd batteries in parallel configuration (Modular Power Subsystem (MPS))
- 22 series cells per battery
- Plate fabrication
 - positive in 5/85
 - negative in 1 - 2/85
- Cell activation in 3/88
- Launched on 6/7/92
- Completed 2470 eclipse orbits
- Nominal performance
 - VT 4; recharge ratio 1.07 - 1.08; temperature : changed from -1°C to 2°C on 9/8/92, to 4.5°C on 9/15/92, and to 7.5°C on 10/23/92 ; and average DoD 9% (maximum 10%)

UARS

- Three 50 Ah conventional NiCd batteries in parallel configuration (MPS)
- 22 series cells per battery
- Plate fabrication
 - positive in 8 - 11/88
 - negative in 11/88 - 1/89
- Cell activation in 10/30/89
- Launched on 9/12/91
- Completed 1730 eclipse orbits and 139 full sun orbits during the first four months with nominal performance
 - VT 6/5, recharge ratio 1.09 - 1.15, temperature 2 - 4°C and average DoD 6 - 18% (maximum 20%)
- After high beta angle, about 40 mV half-battery differential voltage on 1/92

UARS - continued

- VT levels 5 and 6, and successive high beta angle increased the half-battery differential voltage up to 500 mV
- Monitored and managed battery performance since 5/92 by adjusting solar ray offset or power demand control battery charge/discharge ratio or disable/enable VT control
 - completed 6219 eclipse orbits and 139 full sun orbits
 - VT 4, recharge ratio 1.02 - 1.07, temperature 3 - 9°C and average DoD 6-18 % (maximum 22%)

GRO

- Two sets of three 50 Ah conventional NiCd batteries
in parallel configuration
 - MPS 1
 - MPS 2
- 22 series cells per battery
- Launched on 4/5/91

GRO MPS 1

- Plate fabrication
 - positive in 9 - 10/88
 - negative in 6 - 11/88

- Cell activation in 7/89

- Nominal performance up to 3174 eclipse orbits
 - VT 5, recharge ratio 1.1 (uncorrected), temperature 1°C, and average DoD 10% (maximum 12%)
- About 80 mV half-battery differential voltage on 12/91
- Lowered VT level to 4 on 2/92
 - half-battery differential voltage increased to 450 mV in the next 4 months

GRO MPS 1 - continued

- Lowered VT level to 3 on 5/92
 - battery #2 half-battery differential voltage reached 699 mV and half-battery differential voltage reached 200 - 400 mV for Batteries #1 and #3 on 7/2/92
- Performance of battery#2 degraded even after load shedding, and VT switching or VT control inhibition
 - half-battery differential voltage reached again 699 mV and temperature reached greater than 28°C on 7/16/92
 - cell short, battery #2 disabled
- Monitored and managed battery performance since 9/15/92 by charging at 0.8 A constant current for the first 15 minutes of the day, and then usual VT control at level 3 with taper
 - completed 9150 eclipse orbits
 - VT 3, recharge ratio 1.2 - 1.3 (uncorrected), temperature 1°C, average DoD 4% (maximum 6%) and half-battery differential voltage up to 200 mV

GRO MPS 2

- Plate fabrication
 - positive in 7/85
 - negative in 1 - 3/85
- Cell activation in 11/88
- Completed 9166 eclipse orbits
- Nominal performance
 - VT 6, recharge ratio 1.1 (uncorrected), temperature 2 - 4°C, and average DoD 14% (maximum 16%)

ERBS

- Two 50 Ah conventional NiCd batteries in parallel configuration (MPS)
- 22 series cells per battery
- Plate fabrication
 - positive in 6 - 9/83
 - negative in 6 - 9/83
- Cell activation in 11/83
- Launched on 10/4/84
- Completed 19500 eclipse orbits and 2500 full sun orbits during the first four years with nominal performance
 - VT 6, recharge ratio 1.08, temperature 10°C and average DoD 9% (maximum 50%)

ERBS - continued

- Half-battery differential voltage up to 200 mV for battery #1 and up to 1 V for battery #2 during the last three quarters of 90, 91, and the first six months of 92
- Cell short in battery #1 on 8/7/92
 - lowered VT level from 4 to 3
- Second cell short in battery #1 on 9/4/92
 - battery #1 disabled
 - raised VT level first to 4 and then to 5
- Completed 39200 eclipse orbits and 5000 full sun orbits with nominal performance
 - VT 5, recharge ratio 1.08, temperature 7°C and average DoD 12% (maximum 18%)

HST

- Six 88 Ah Ni-H₂ batteries in two three-battery modules (Flight Spare Module(FSM) and Flight Module 1(FM2))
- Common bus for all batteries to operate at a common voltage
- 22 series cells per battery
- Positive plate fabrication
 - FSM in 2 - 6/88
 - FM2 in 6 - 11/88
- Cell activation
 - FSM in 1/89
 - FM2 in 3/89
- Launched on 4/24/90

HST - continued

- Reconditioned batteries #1 and #4 through 5.1 ohm load to about 19 V on 12/90
 - capacity dropped to about 65 Ah
 - capacity recovered to 75 Ah in two weeks and recovered to 89 Ah in 20 months
- Reconditioned batteries #5, #2, #6 and #3 through 5.1 ohm load to about 13 V on 8-9/92
 - capacity dropped to about 63 Ah
 - capacity recovered to about 68 Ah in two weeks
 - current system capacity recovery rate 0.4 Ah per day
- Completed 13987 eclipse orbits
- Nominal performance
 - VT levels K1L3 and K2L3, trickle charge current 12 A and period 42 minutes, recharge ratio 1.06 - 1.13 (time based), temperature -3 - 3°C, average DoD 5 - 8% (maximum 8.5%), and system capacity 480 Ah

LIFE CYCLE TESTING AT NSWC, CRANE

- Advanced NiCd cells from Hughes Aircraft Company/Eagle Picher Industries, Inc., Colorado Springs
- Conventional NiCd cells from Gates Aerospace Batteries (GAB)
- Conventional NiCd cells from General Electric
- NiCd cells from SAFT
- NiH₂ cells from Eagle Picher Industries, Inc., Joplin
- Data as of 10/26/92

ADVANCED NICD CELL LIFE CYCLE TEST

- Pack # 6000A - 21 Ah, Polypropylene, PBI
- Pack # 6001A - 21 Ah, Zircar/Polysulfone
- Pack # 6002A - 21 Ah, Zircar/PBI
- Pack # 6003A - 21 Ah, Zircar/Polysulfone
- Pack # 6004A - 21 Ah, Zircar/Polysulfone
- Pack # 6005A - 21 Ah, Zircar/Polysulfone
- Pack # 6006A - 21 Ah, Zircar/PBI w/ additive
- Pack # 6053A - 21 Ah, Zircar/PBI w/ additive
- Pack # 0090A - 9 Ah, Zircar/PBI w/ additive
- Pack # 0090B - 9 Ah, Zircar/PBI w/ additive

ADVANCED NICD CELL LIFE CYCLE TEST- continued

Pack #	SIZE	ORBIT	DoD	TEMP C/D	VTEOD	CYCLE #
	Ah		%	°C	V	
6000A	21	LEO	40	20	1.03	6 1.064 15278
6001A	21	LEO	40	20	1.03	6 1.026 15190
6002A	21	LEO	40	20	1.01	6 1.073 15110
6003A	21	LEO	40	20	1.04	6 1.038 13872
6004A	21	LEO	25	30	1.03	6 0.999 13819
6005A	21	LEO	40	30	1.04	7 0.972 13744
6006A	21	LEO	40	20	1.02	6.5 1.077 13212
6053A	50	LEO	40	20	1.04	6 1.095 6551
0090A	9	LEO	40	30	1.16	7 1.134 2652
0090B	9	LEO	0-18	5	1.07	4 1.235 782

GAB NICD CELL LIFE CYCLE TEST

Pack #	SIZE	ORBIT	DoD	TEMP C/D	VT EOD	CYCLE #
	Ah	%	°C	V		
6051D	50	LEO	40	20	1.01	7 0.975 18030 (EUVE)
6051F	50	LEO	40	20	1.01	6 0.952 14471
6051G	50	LEO	40	20	1.01	6 0.974 14376 (GRO-MPS2)
6051I	50	LEO	15	15	1.06	6 1.217 12433 (EUVE AND GRO-MPS2)
6051H	50	LEO	40	20	1.01	6 1.101 11941 (GRO-MPS1)
6052A	50	LEO	18	0	1.03	4 1.218 6222 (UARS)
6052B	50	LEO	18	0	1.03	2 1.115 5687 (UARS)

(UP TO 5380 CYCLES: DoD - 40% AND 20°C)
(UP TO 4356 CYCLES: DoD - 21.5% AND 15°C)

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #6051H (GRO-MPS1)

- Started testing on 6/90 with 40% DoD at 20°C
- Cell voltage divergence first seen around 6600 cycles
- Maximum cell voltage divergence around 7500 cycles
 - EOC about 36 mV
 - EOD about 123 mV
- Gradual recovery with cycling
 - Cell voltage divergence around 9200 cycles
 - EOC about 12 mV
 - EOD about 10 mV
- Stopped testing after 11941 cycles
- No second voltage plateau during the capacity check

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #6052A (UARS)

- Started testing on 5/91 with 40% DoD at 20°C and VT6
 - Cell voltage divergence first seen around 1500 cycles and increased with cycling
 - Cell voltage divergence around 5300 cycle
 - EOC about 31 mV
 - EOD about 52 mV
- Moved to 0°C at 5380th cycle
 - Cell voltage divergence around 5477 cycle
 - EOC about 40 mV
 - EOD about 60 mV
- One cell (S/N2-7) removed for DPA at 5508th cycle
- Continued testing with 4 cells under UARS profile at 5510th cycle
 - 34.5 A charge current followed by a linear decrease in current for the first 16.5 minutes and then at 18.3 A constant current with VT taper
 - 18% DoD

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #60052A (UARS) - continued

- Cell voltage divergence around 5585 cycle
 - EOC about 10 mV
 - EOD about 10 mV
- Changed VT level to 4 at 5591th cycle
 - Cell voltage divergence around 5844 cycle
 - EOC about 53 mV
 - EOD about 26 mV
- Another cell (S/N2-21) removed for DPA at 5846th cycle
- Stopped testing after 6222 cycles
 - Cell voltage divergence
 - EOC about 34 mV
 - EOD about 0 mV
- Second voltage plateau around 1 V during the capacity check

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #6052B (UARS)

- Started testing on 5/91 with 21.5% DoD at 15°C, 18.3 A constant current charge rate, and VT6
 - Cell voltage divergence first seen around 2000 cycles and increased with cycling
 - EOD voltage decline began around 2000 cycles and continued with cycling
 - Cell voltage divergence around 2530 cycle
 - EOC about 40 mV
 - EOD about 30 mV
- Moved to 0°C at 5380th cycle
 - Cell voltage divergence around 5477 cycle
 - EOC about 40 mV
 - EOD about 60 mV
- Started testing under UARS profile at 4357th cycle
 - 34.5 A charge current followed by a linear decrease in current for the first 16.5 minutes and then at 18.3 A constant current with VT taper
 - 18% DoD and 0°C

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #6052B (UARS) - continued

- Rapid increase in cell voltage divergence during the 4393th charge cycle and the high values during the subsequent charge/discharge cycles
 - EOC about 105 mV
 - EOD about 142 mV
- No improvement after trickle charging at 0°C and 20°C
- Continued cycling at 20°C
 - Cell voltage divergence around 4946 cycle
 - EOC about 55 mV
 - EOD about 120 mV
- One cell (S/N2-73) removed for DPA at 4947th cycle

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #6052B (UARS) - continued

- Moved to 0°C at 5101th cycle
 - Cell voltage divergence around 5132 cycle
 - EOC about 187 mV
 - EOD about 39 mV
- Changed charge rate to 25 A constant current with VT 2 taper at 5298th cycle
 - Cell voltage divergence around 5370 cycle
 - EOC about 100 mV
 - EOD about 70 mV
- Stopped testing after 5687 cycles
 - Cell voltage divergence
 - EOC about 23 mV
 - EOD about 113 mV
- Second voltage plateau around 1 V during the capacity check

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #	SIZE	ORBIT	DoD	TEMP C/D	VT EOD	CYCLE
#	Ah		%	°C		V
6051C	50	LEO	40	20	1.01	6 0.937 17169
6051E	50	LEO	40	20	1.01	6 0.958 15505
6053B	50	LEO	40	20	1.04	6 1.032 6455
6085A	20	LEO	20	15	1.06	6 1.221 11945
6085B	20	LEO	28	15	1.08	6 1.067 10420
6085C	20	LEO	40	20	1.01	6 1.075 14699

GAB NICD CELL LIFE CYCLE TEST - CONTINUED

Pack #	SIZE	ORBIT	DoD	TEMP	EOD	SHADOW#
Ah			%	°C	V	
0231A	6	GEO(IUE)	80	10	1.157	30
0232A	40	GEO(TDRSS)	50	0	1.187	27
0232B	40	GEO(TDRSS)	50	15	1.188	24
0232C	40	GEO(TDRSS)	75	0	1.162	21
0232D	40	GEO(TDRSS)	75	0	1.183	1
6232A	40	GEO(TDRSS)	50	0	1.190	21
6232B	40	GEO(TDRSS)	50	0	1.200	1
6232C	40	GEO(TDRSS)	50	10	1.185	45
6232D	40	GEO(TDRSS)	50	15	1.196	40
6227B	12	GEO(GOES)	60	10	1.173	7
6227C	12	GEO(GOES)	60	10	1.138	7

GENERAL ELECTRIC NICD CELL LIFE CYCLE TEST

Pack #	SIZE	ORBIT	DoD	TEMP C/D	VT EOD	CYCLE #
Ah	%	°C	V			
0004H	4	HEO?	40	15	3.54	6 1.184 4136
0026G	26.5	LEO	20	10	1.01	3.5 1.063 68480
0028I	26.5	LEO	18.5	10	1.02	4 1.231 43000
0026J	26.5	LEO	25	10	1.04	4 1.121 29328

SAFT NICD CELL LIFE CYCLE TEST

Pack #	SIZE	ORBIT	DoD	TEMP C/D	VT EOD	CYCLE #
Ah			%	°C	V	
6024S	24	LEO	40	0	1.03	6.5 1.115 19761
6124S	24	LEO	40	20	1.02	7 0.972 19501
6120S	20	LEO	40	20	1.05	7 1.024 19359

NiH₂ CELL LIFE CYCLE TEST

Pack #	SIZE	ORBIT	DoD	TEMP C/D	VT	EOD	CYCLE #
3600H	93 Ah	LEO	9%	-3.5 °C	1.02 V	1.52	1.311 2149
FM1							
3600H	93 Ah	LEO	9%	-3.5 °C	1.02 V	1.52	1.312 2160
FM2							